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Davies et al.

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(54) **MONOLITHICALLY INTEGRATED TUNABLE SEMICONDUCTOR LASER**

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H01S 5/026 (2006.01)

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CPC H01S 5/026; H01S 5/125; H01S 3/08
USPC 372/20
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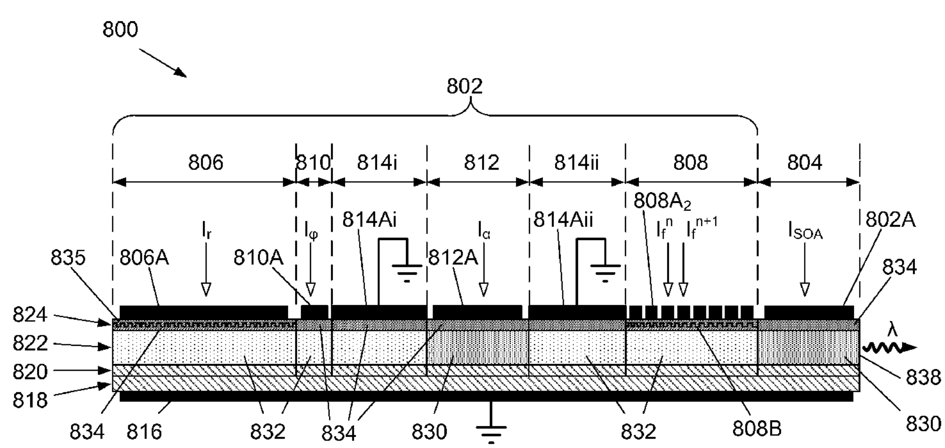
(57) **ABSTRACT**

A monolithically integrated, tunable semiconductor laser with an optical waveguide, comprising a laser chip having epitaxial layers on a substrate and having first and second reflectors bounding an optical gain section and a passive section, wherein at least one of the reflectors is a distributed Bragg reflector section comprising a grating and configured to have a tunable reflection spectrum, wherein the laser is provided with a common earth electrode, wherein control electrodes are provided on the optical waveguide in at least the optical gain section and the at least one distributed Bragg reflector section, wherein the passive section is provided with an electrode or electrical tracking on the optical waveguide, the passive section is configured not to be drivable by an electrical control signal, and no grating is present within the passive section.

16 Claims, 10 Drawing Sheets



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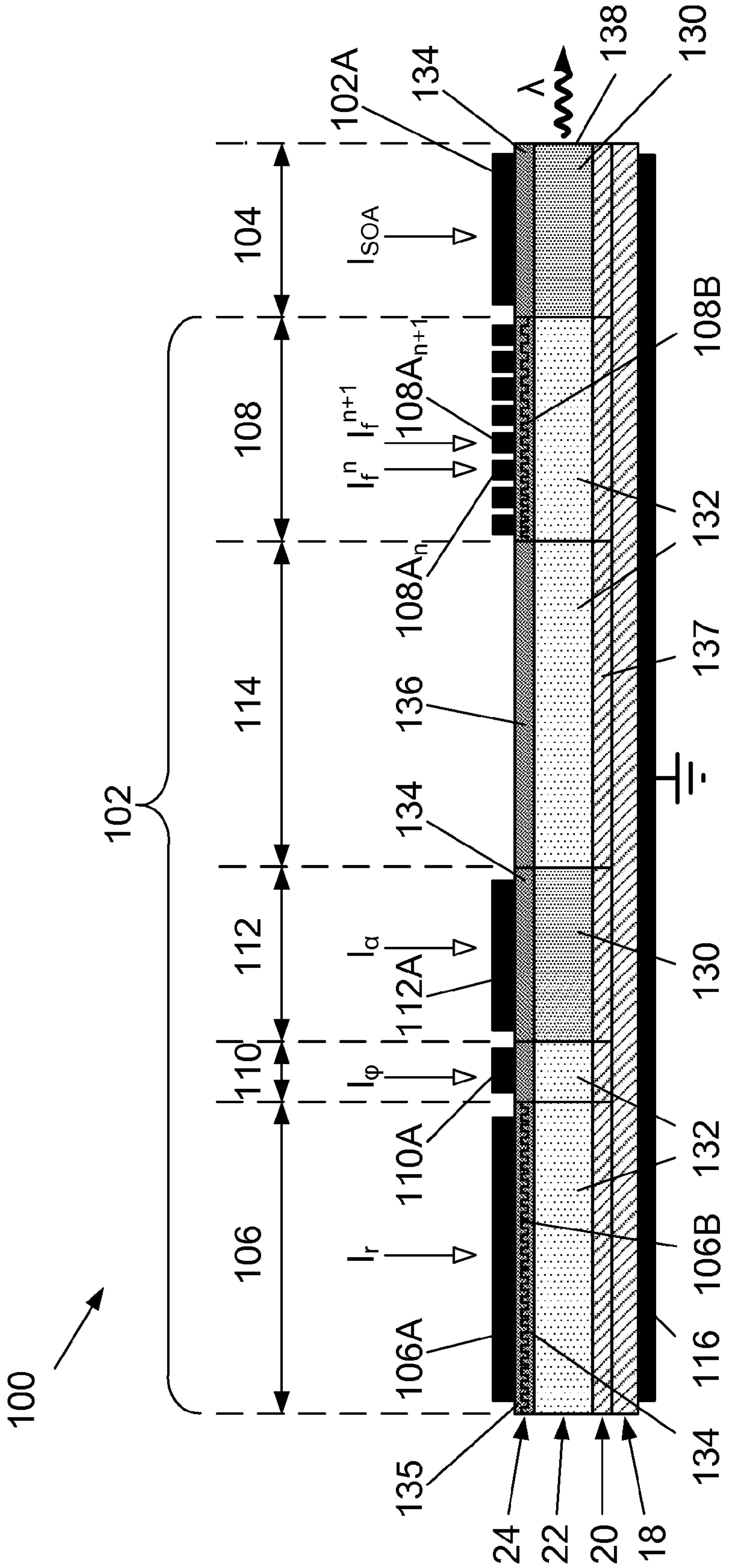


100
102
102A
104
108
114
112
110
106
134
λ
138
130
I_{SOA}
I_f^n
I_f^{n+1}
108A$_{n+1}$
108B
108A$_n$
136
132
137
I_α
112A
I_φ
110A
I_r
106A
106B
116
135
124
122
120
118

Figure 1A

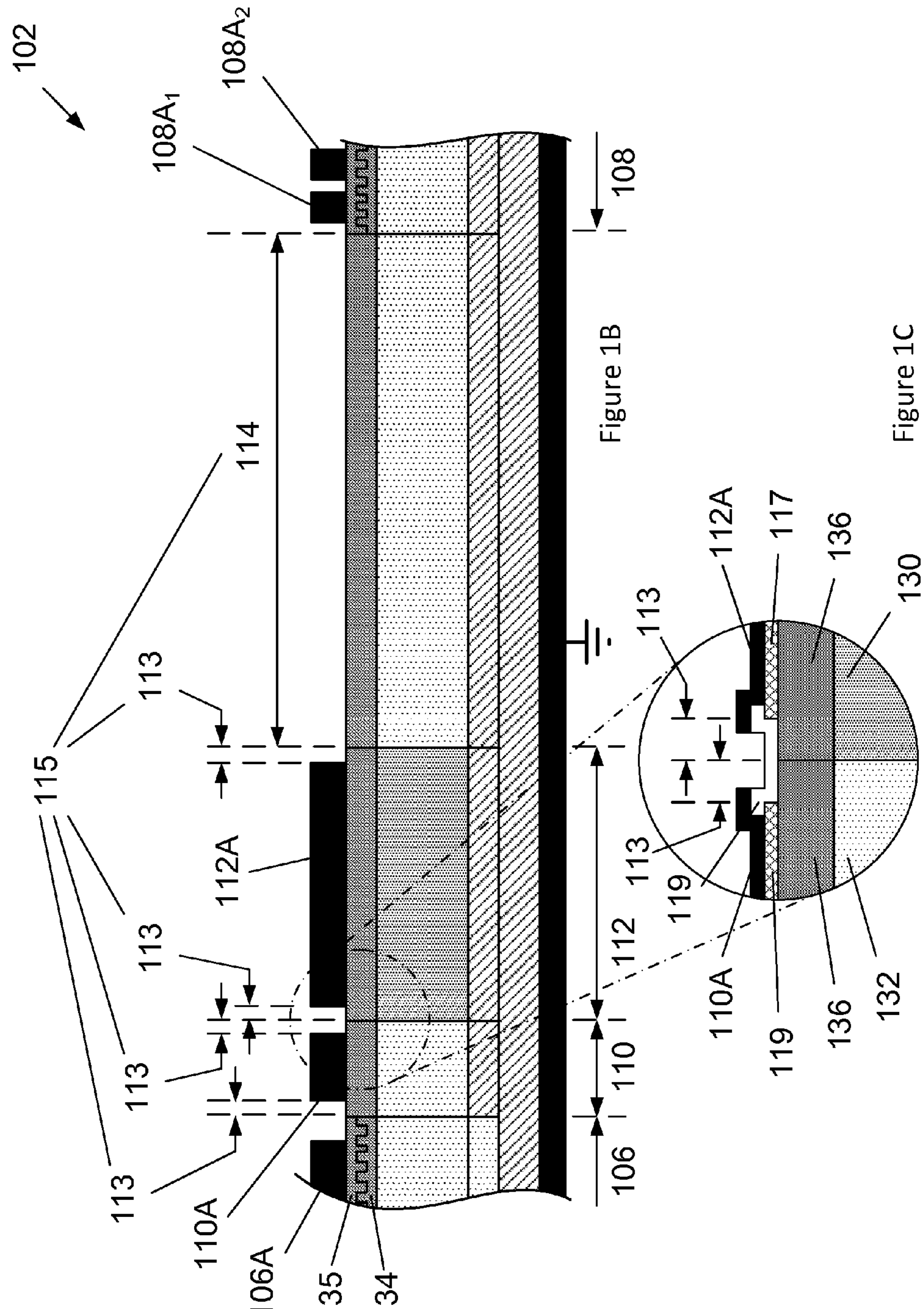


Figure 1B

Figure 1C

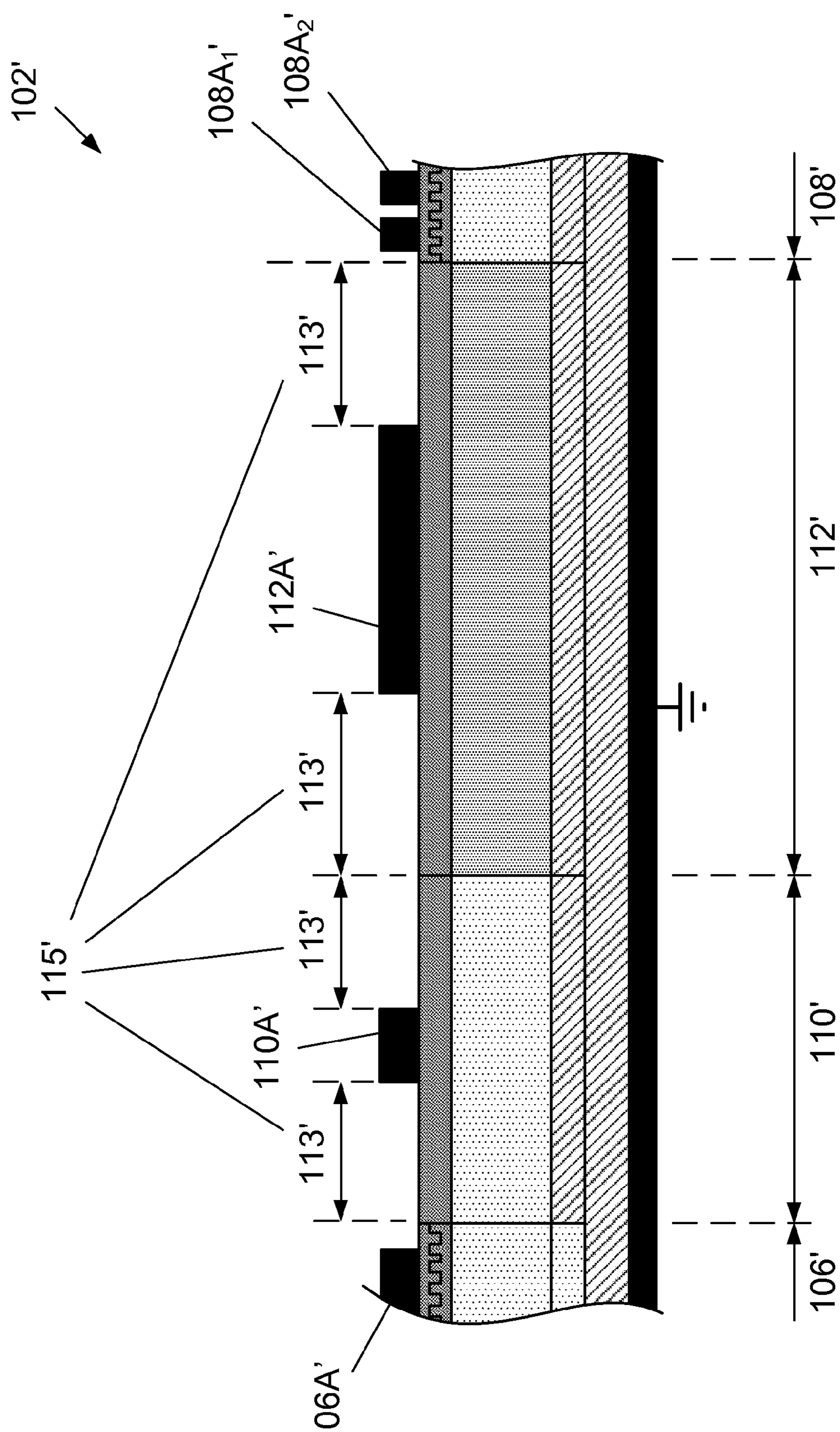

102'
108A1'
108A2'
108'
113'
112A'
112'
113'
113'
110A'
110'
113'
115'
106'
106A'

Figure 1D

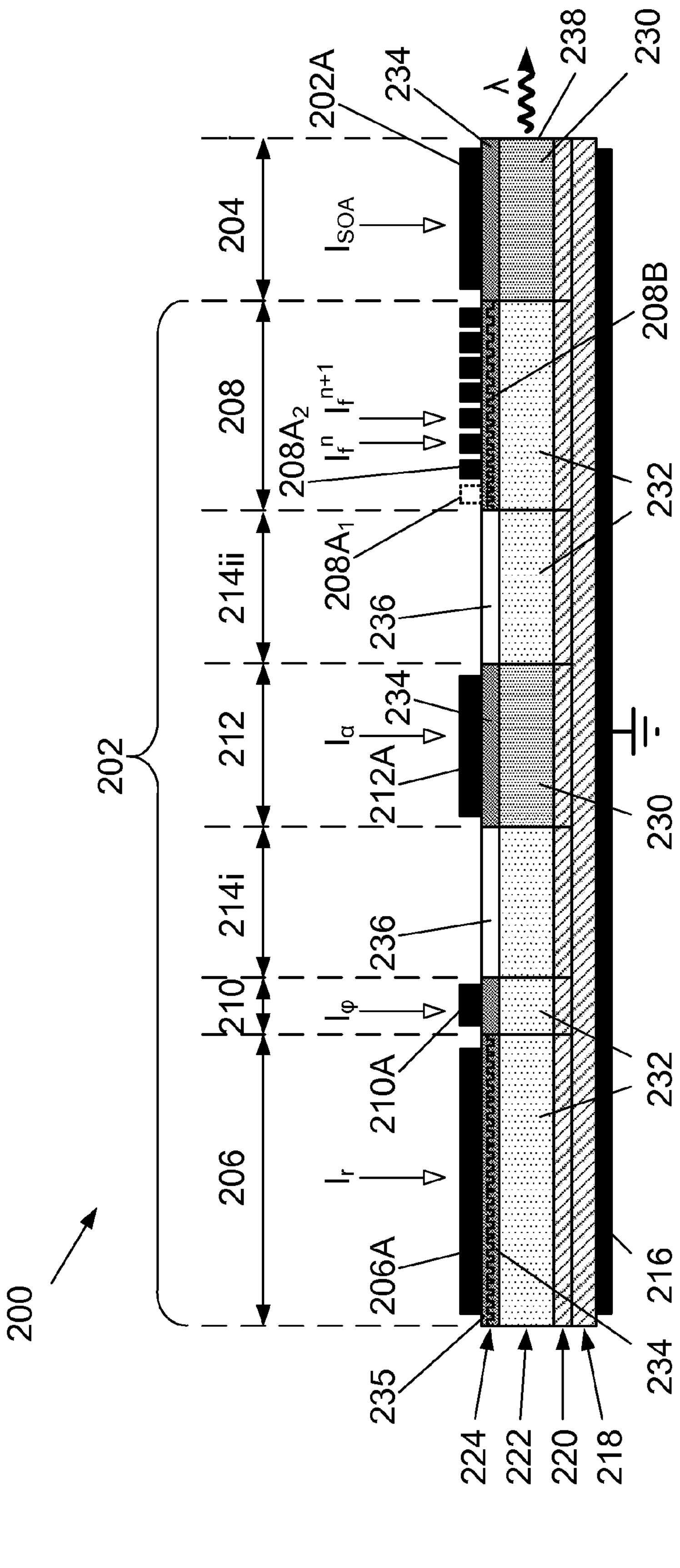
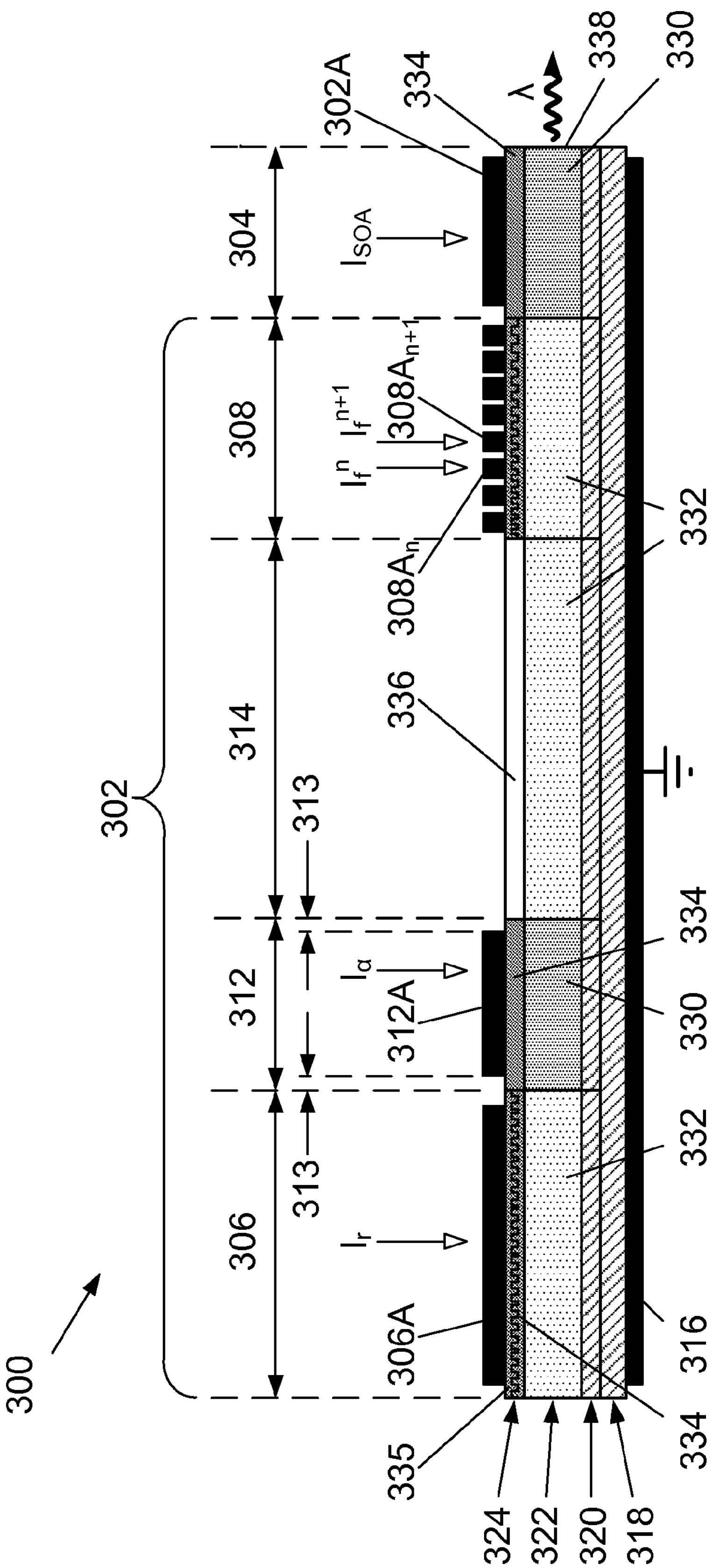
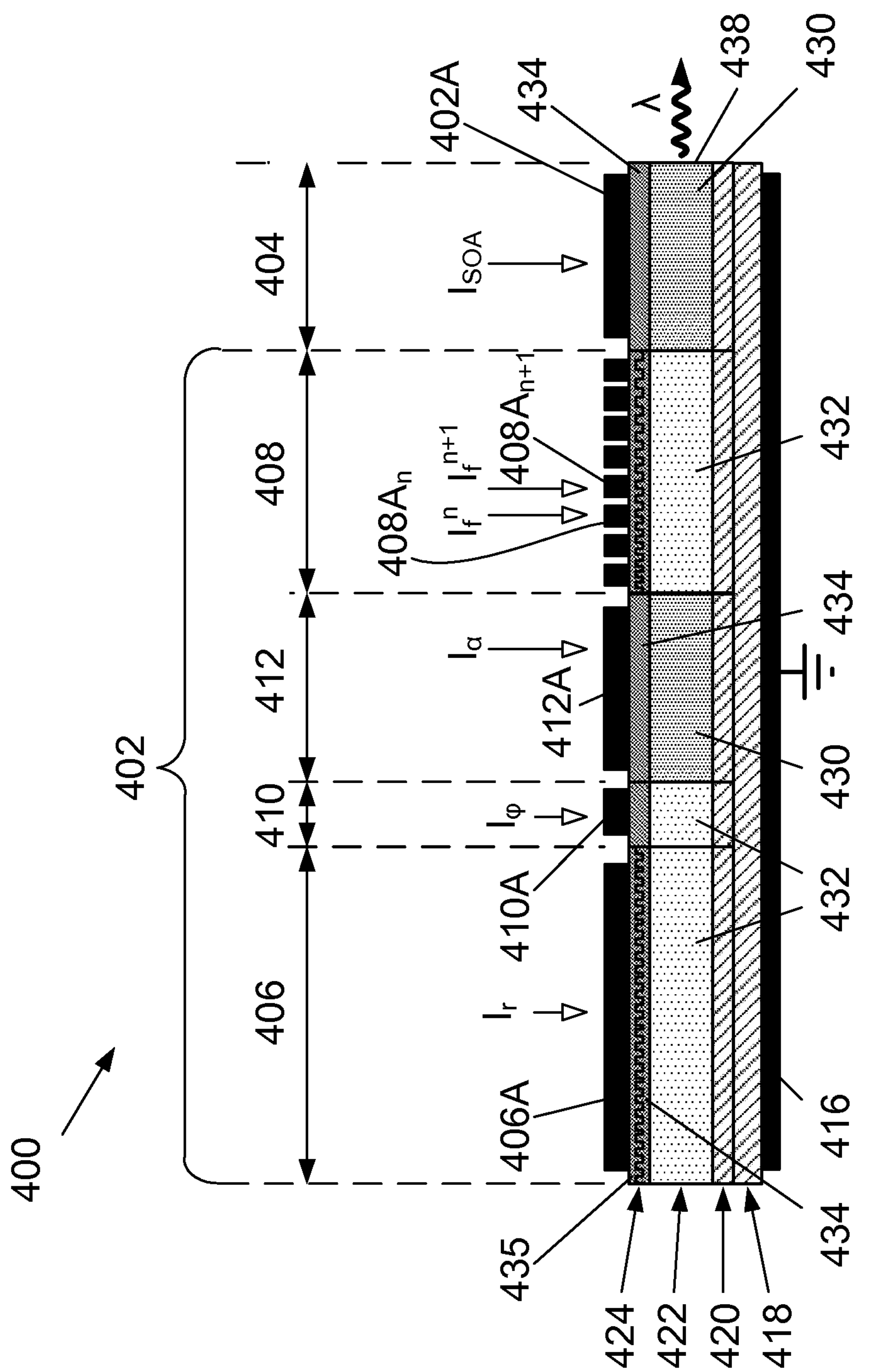

200
202
202A
204
206
206A
208
208A$_1$
208A$_2$
208B
210
210A
212
212A
214i
214ii
216
218
220
222
224
230
232
234
235
236
238
I_{SOA}
I_f^n
I_f^{n+1}
I_α
I_φ
I_r
λ

Figure 2



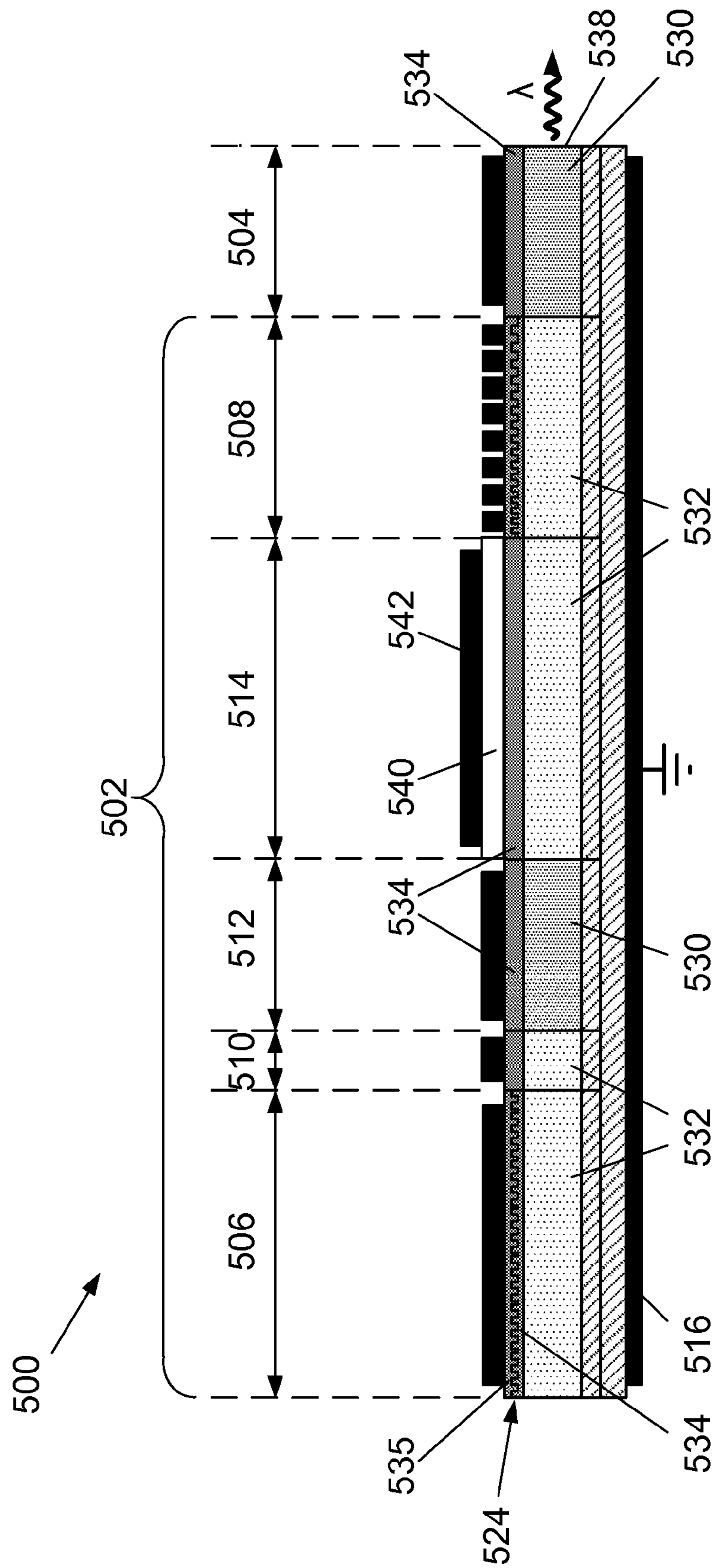
300
302
302A
304
I_{SOA}
308
I_f^n
I_f^{n+1}
$308A_{n+1}$
$308A_n$
314
336
313
312
I_α
312A
306
I_r
306A
335
334
338
330
332
316
λ
324
322
320
318

Figure 3



400
402
404
406
408
410
412
402A
434
λ
438
430
I_{SOA}
$408A_{n+1}$
I_f^{n+1}
I_f^n
$408A_n$
432
I_α
412A
430
432
I_φ
410A
432
I_r
406A
416
434
435
424
422
420
418

Figure 4



534
λ
538
530
504
502
508
532
514
542
540
534
512
530
510
532
506
500
516
534
535
524

Figure 5

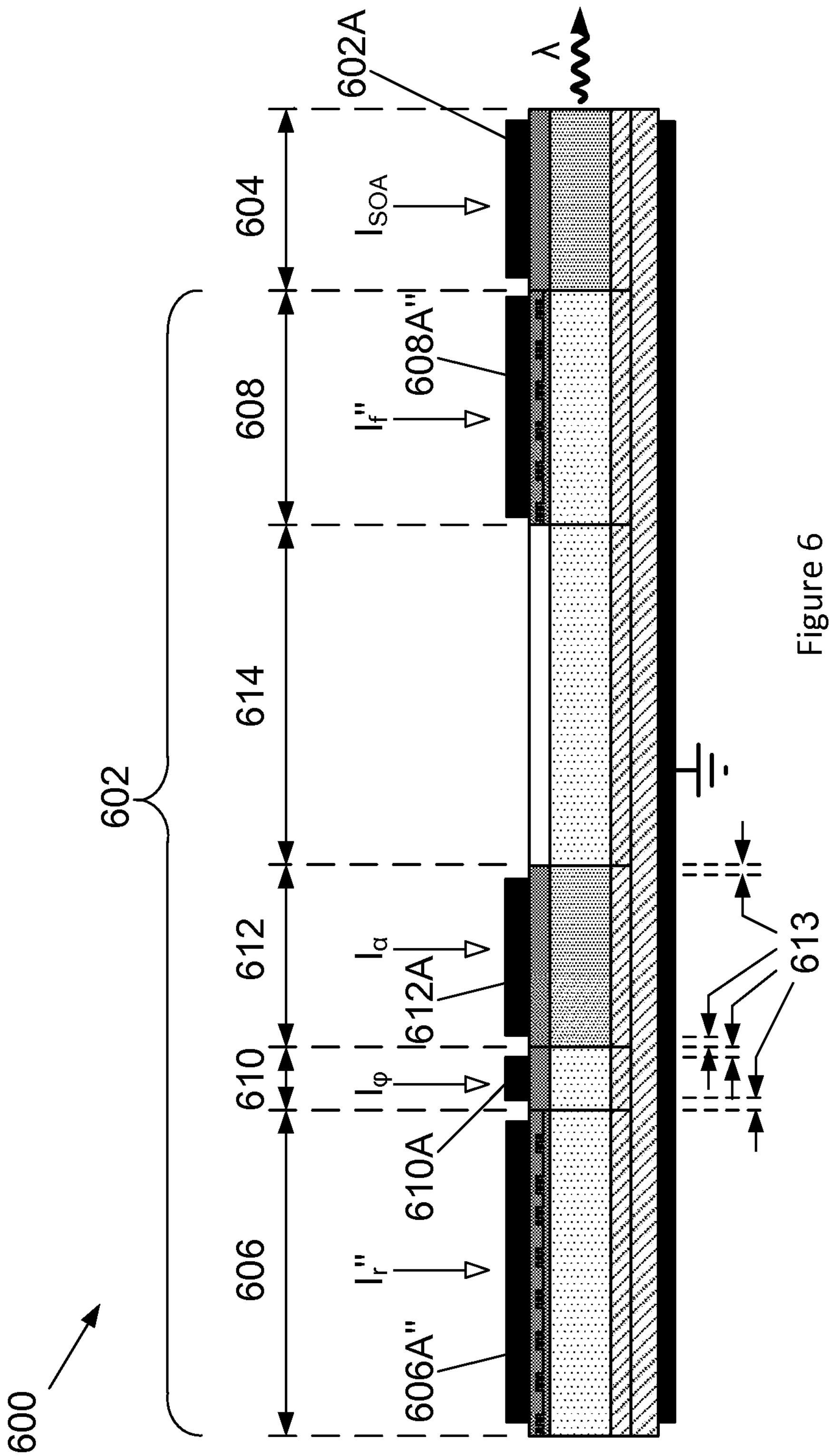

600
602
602A
λ
604
I_{SOA}
608A"
608
I_f"
614
612
I_α
612A
610
I_φ
610A
606
I_r"
606A"
613

Figure 6

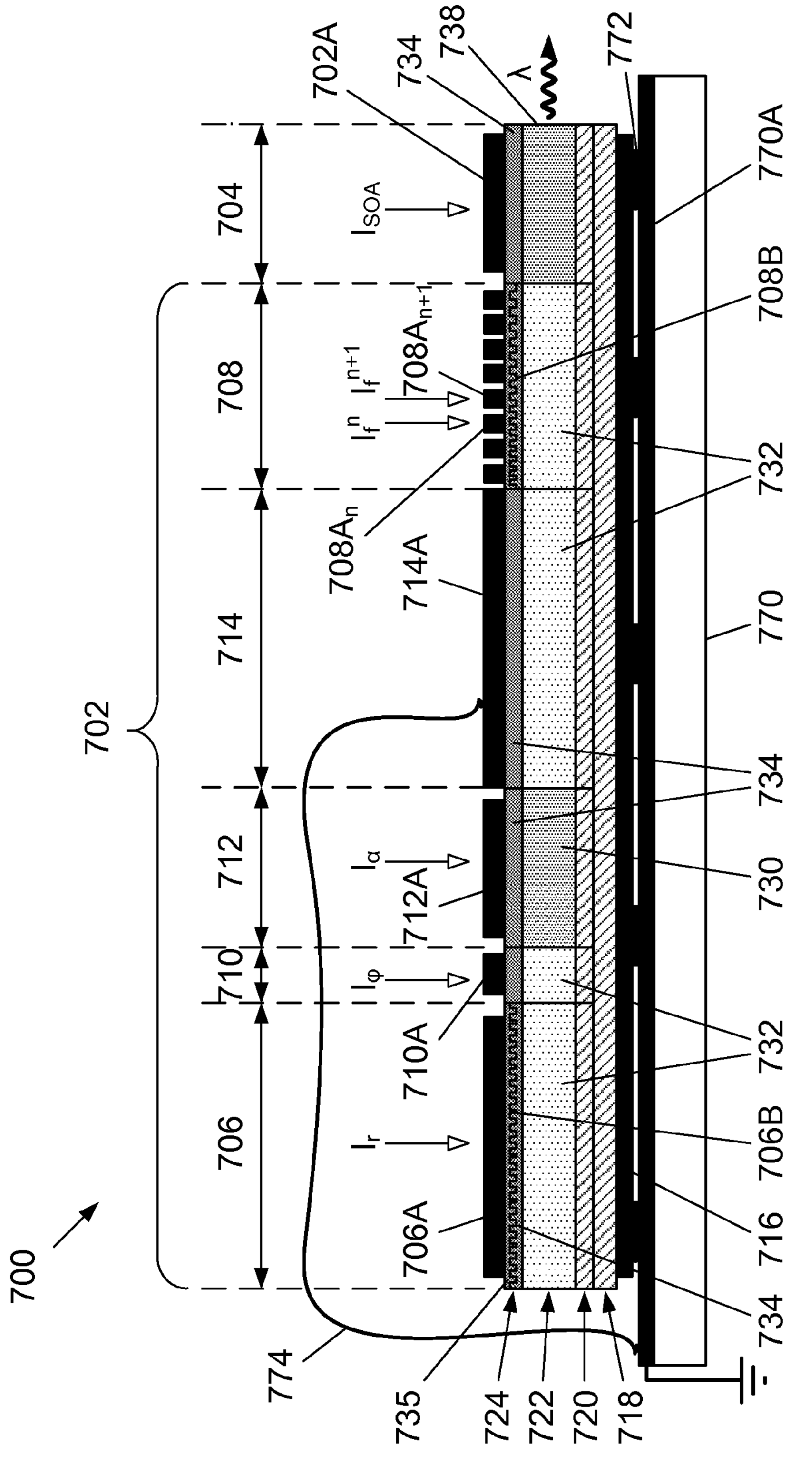
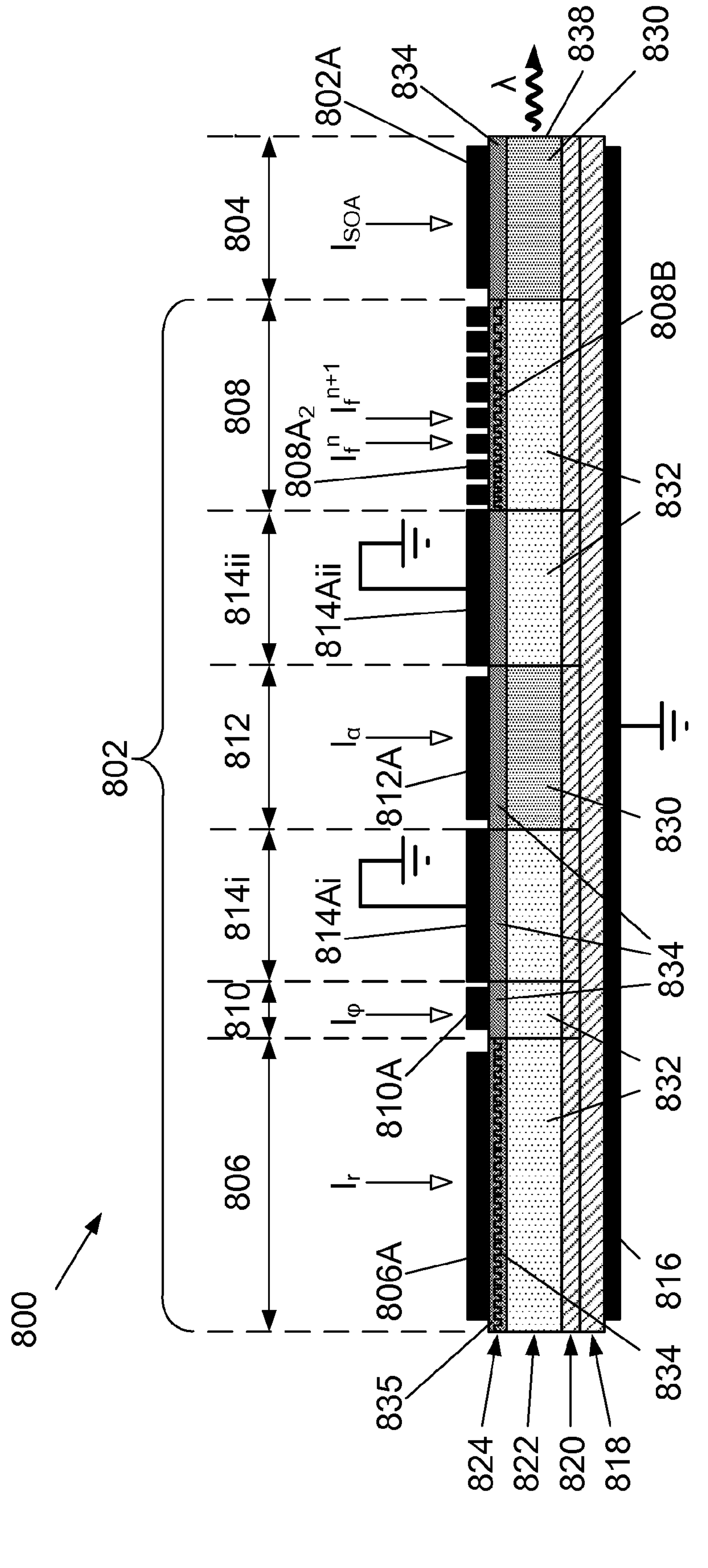

700
702
702A
704
706
706A
706B
708
708A$_n$
708A$_{n+1}$
708B
710
710A
712
712A
714
714A
716
718
720
722
724
730
732
734
735
738
770
770A
772
774
I_{SOA}
I_f^n
I_f^{n+1}
I_α
I_φ
I_r
λ

Figure 7



800
802
802A
834
λ
838
830
804
I_{SOA}
808B
808
I_f^n I_f^{n+1}
$808A_2$
832
814ii
814Aii
812
I_α
812A
830
814i
814Ai
834
810
I_φ
810A
832
806
I_r
806A
816
834
835
824
822
820
818

Figure 8

MONOLITHICALLY INTEGRATED TUNABLE SEMICONDUCTOR LASER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation in part of U.S. application Ser. No. 14/240,545, filed Feb. 24, 2014, which is a 371 of International Application No. PCT/GB2012/052086, filed Aug. 24, 2012, which claims priority to United Kingdom Application No. 1114822.8, filed on Aug. 26, 2011, each of which are incorporated by reference in their entirety.

FIELD OF DISCLOSURE

The present invention relates to wavelength tunable, monolithically integrated semiconductor lasers having a tunable distributed Bragg reflector, more particularly to such lasers for use in telecommunications applications.

BACKGROUND

Monolithically integrated semiconductor tunable lasers are widely used in the telecommunications industry for transmitting optically modulated light along optical fibres. Commonly, in such applications, the optical signals of many lasers are wavelength division multiplexed (WDM) or densely wavelength division multiplexed (DWDM) with transmission on standardised transmission channels. Two principal telecommunications bands, namely the C Band (191.6-196.2 THz) and the L Band (186.4-191.6 THz), have standard wavelength channels defined by the International Telecommunications Union (ITU) at spacings of 100 GHz (0.8 nm), 50 GHz (0.4 nm), or 25 GHz (0.2 nm). As well as requiring stability in the transmission wavelength, such wavelength multiplexed systems require the transmitting lasers to have a narrow linewidth. Laser linewidth is particularly significant in coherent transmission systems, in which a laser is provided both in the transmitter and in the receiver of each transmission link.

Historically, simple single longitudinal mode lasers with short lasing cavities were widely deployed and capable of operation on only one channel or tunable across a small number of channels, with their operating wavelengths being thermally stabilised through control of the operating temperature of each laser. However, more recently, lasers that are widely wavelength tunable have found favour with network providers. U.S. Pat. No. 7,145,923 describes such a design of widely tunable laser.

The lasing cavities of widely tunable lasers require a pair of lengthy, tunable distributed Bragg reflector sections (DBRs), a gain section and a phase control section on a common waveguide, in order to operate on a single longitudinal cavity mode. The DBRs are provided by gratings within the optical waveguide of the laser, and are tuned to control the lasing wavelength of the laser cavity. However, these DBR sections increase the length of the laser cavity, which results in more closely spaced longitudinal modes of the laser cavity. Effective transmission of an optical signal requires uninterrupted transmission on a single, wavelength stabilised longitudinal mode with a high level of discrimination between the intensity of the dominant lasing mode and unwanted side modes. To provide a high level of side mode suppression (i.e. a high side mode suppression ratio, SMSR) it has been necessary to minimise the length of the optical cavity of the laser. To reduce electrical interference, narrow electrical isolation regions are provided between the control electrodes that are over adjacent sections of the laser. The length (along the waveguide) of such isolation regions is kept to a minimum, being no more than a few μm (i.e. significantly less than 20 μm).

The present inventors have identified that, disadvantageously, the requirement for short laser cavities results in the production of optical outputs from the lasers with significant linewidths, commonly having a linewidth dominated by the population of photons within the laser cavity and by the round trip time of the laser cavity.

SUMMARY OF THE DISCLOSURE

According to a first aspect, there is provided a monolithically integrated, tunable semiconductor laser with an optical waveguide, comprising a laser chip having epitaxial layers on a substrate and having

first and second reflectors bounding

an optical gain section and

a passive section,

wherein at least one of the reflectors is a distributed Bragg reflector section comprising a grating and configured to have a tunable reflection spectrum,

wherein the laser is provided with a common earth electrode,

wherein control electrodes are provided on the optical waveguide in at least the optical gain section and the at least one distributed Bragg reflector section,

wherein the passive section is provided with an electrode or electrical tracking on the optical waveguide, the passive section is configured not to be drivable by an electrical control signal, and no grating is present within the passive section.

Advantageously, the lasers of the present invention may have a reduced linewidth/phase noise, compared with known devices.

According to a second aspect, there is provided a monolithically integrated, tunable semiconductor laser with an optical waveguide, comprising a laser chip having epitaxial layers on a substrate and having first and second reflectors bounding an optical gain section and a grounded passive section, wherein at least one of the reflectors is a distributed Bragg reflector section comprising a grating and configured to have a tunable reflection spectrum, wherein the laser is provided with a common earth electrode, wherein control electrodes are provided on the optical waveguide in at least the optical gain section and the at least one distributed Bragg reflector section, wherein the grounded passive section is provided with a grounded electrode on the optical waveguide that is electrically connected to the common earth electrode, and no grating is present within the grounded passive section.

According to a third aspect, there is provided a monolithically integrated, tunable semiconductor laser having an optical gain section, an optical phase control section, and a grounded passive section bounded at one end by a tunable first Bragg reflector in the form of a distributed Bragg reflector adapted to produce a comb of reflective peaks and at the other end by a tunable second distributed Bragg reflector, the second distributed Bragg reflector being adapted to reflect at a plurality of wavelengths, wherein one or more wavelengths of reflective peaks of the first distributed Bragg reflector substantially coincide with one or more wavelengths at which the tunable second distributed Bragg reflector reflects prior to each of the first and second distributed Bragg reflectors being tuned, and wherein the second distributed Bragg reflector is capable of being tuned selectively through discrete segments so that one or more segments of the second distributed Bragg reflector can be tuned to a lower wavelength to reflect with a further segment of the second distributed Bragg reflector reflecting at that lower wavelength to enhance the reflectivity at that lower wavelength, the lower wavelength substantially coinciding with a peak of the first distributed Bragg reflector, thereby capable of causing the laser to lase at that lower wavelength, wherein the passive section is provided with an electrode or electrical tracking on the optical waveguide, the passive section is configured not to be drivable by an electrical control signal, and no grating is present within the passive section.

According to a fourth aspect, there is provided a monolithically integrated, tunable semiconductor laser array comprising a plurality of lasers according to the first or second aspect that are optically coupled to a common optical output.

According to a fifth aspect, there is provided an optical transmitter module comprising a monolithically integrated, tunable semiconductor laser or a monolithically integrated, tunable semiconductor laser array according to the first, second or third aspect and control electronics configured to control the operation of the laser or laser array.

The passive section may be a grounded passive section in which the electrode is a grounded electrode that electrically contacts the passive section and is electrically connected to the common earth electrode.

Advantageously, the grounded passive section may reduce the contribution to the linewidth/phase noise from shot noise.

The common earth electrode may be provided on the substrate, the common earth electrode may be bonded to a mounting element electrode provided on a mounting element, and the grounded electrode may be electrically connected to the mounting element electrode.

An electrically insulating layer may be provided on the optical waveguide in the passive section, and the electrode or electrical tracking may be provided on the electrically insulating layer.

The grounded passive section may comprise a p-i-n doped epitaxial structure.

The laser may comprises a substrate, a lower layer on the substrate, an overgrowth layer and an optical guiding layer between the lower layer and the overgrowth layer,

wherein the optical waveguide has an optical phase control section bounded by the first and second reflectors, and

the phase control section and the passive section comprises a common overgrowth layer and/or lower layer.

The laser may comprise a plurality of passive sub-sections.

A reflector is an output reflector that is configured for optical output from the laser, and the passive section or a passive sub-section may be located between the optical gain section and the output reflector.

The optical waveguide may have an optical phase control section bounded by the first and second reflectors. The passive section or a passive sub-section may be located between the optical gain section and the optical phase control section.

The passive section may have a length of at least 100 μm. The passive section may have a length of at least 150 μm. The passive section may have a length of at least 200 μm. The passive section may have a length of at least 400 μm.

The control electronics may comprise a control loop configured to sample the wavelength of light output from the laser or laser array and to provide electrical feedback to control electrodes provided on the laser or laser array. Advantageously the electrical feedback is for stabilising the wavelength and/or active suppression of linewidth/phase noise.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates a schematic cross-sectional view of a semiconductor chip comprising a tunable semiconductor laser optically integrated on a common optical waveguide with a semiconductor optical amplifier, having a passive section and a phase control section;

FIG. **1**B shows an enlarged view of part of FIG. **1**A;

FIG. **1**C shows an enlarged view of part of FIG. **1**B;

FIG. **1**D illustrates a schematic cross-sectional view of part of a semiconductor chip comprising a tunable semiconductor laser, having lengthy electrical isolation gaps and a phase control section;

FIG. **2** illustrates a schematic cross-sectional view of a semiconductor chip comprising a tunable semiconductor laser having a plurality of passive sections and a phase control section;

FIG. **3** illustrates a schematic cross-sectional view of a semiconductor chip comprising a tunable semiconductor laser optically integrated on a common optical waveguide with a semiconductor optical amplifier, having a passive section;

FIG. **4** illustrates a schematic cross-sectional view of a semiconductor chip comprising a tunable semiconductor laser optically integrated on a common optical waveguide with a semiconductor optical amplifier, having a phase control section;

FIG. **5** illustrates a schematic cross-sectional view of a semiconductor chip comprising a tunable semiconductor laser, having a passive section and a phase control section, and having an insulating layer over the passive section;

FIG. **6** illustrates a schematic cross-sectional view of a semiconductor chip comprising a further tunable semiconductor laser optically integrated on a common optical waveguide with a semiconductor optical amplifier, having a passive section and a phase control section;

FIG. **7** illustrates a schematic cross-sectional view of a semiconductor chip comprising a tunable semiconductor laser optically integrated on a common optical waveguide with a semiconductor optical amplifier, having a grounded passive section; and

FIG. **8** illustrates a schematic cross-sectional view of a semiconductor chip comprising a tunable semiconductor laser having a plurality of grounded passive sections.

DETAILED DESCRIPTION

In the drawings, like features have been identified with like numerals, albeit in some cases having one or more of: increments of integer multiples of 100. For example, in different figures, **100**, **200**, **300**, **400**, **500**, **600**, **700** and **800** have been used to indicate an optoelectronic semiconductor chip.

FIG. **1**A illustrates a schematic cross-sectional view of an optoelectronic semiconductor chip **100** having a tunable semiconductor laser **102** optically integrated on a common optical waveguide with a semiconductor optical amplifier (SOA) **104**, which is outside the cavity of the laser. The laser **102** has first and second distributed Bragg reflector (DBR) sections **106** and **108** bounding a phase control section **110**, an optical gain section **112** and a passive section **114**. The sections **106**, **108**, **110**, **112** and **114** of the laser **102** are monolithically integrated on the common semiconductor chip **100**.

The chip **100** is provided with a common earth electrode **116** (also referred to as the "back electrode") onto the substrate **118**. The first DBR section **106**, the phase control section **110**, the optical gain section **112**, and the SOA **104** are provided with respective electrical control electrodes, **106**A, **110**A, **112**A and **104**A. The first DBR section **106** comprises a reflective Bragg grating **106**B that produces a reflection spectrum with a comb of reflective peaks. The second DBR section **108** comprises a reflective Bragg grating **108**B with a monotonically chirped grating pitch, with respective sub-electrodes **108**A_1, **108**A_2, etc. provided on segments of the second DBR section arranged along the optical waveguide. No electrode is provided onto the passive section **114** (i.e. the passive section is configured not to be electrically controlled by injection of current into that portion of the optical waveguide passing through the passive section).

As is conventional in optoelectronic structures, the chip **100** comprises a common substrate **118** and a series of epitaxially grown layers successively built up on the substrate, being a lower layer **120**, an optical guiding layer **122**, and an overgrowth layer **124**. Further layers may also be provided (e.g. a patterned layer of highly doped material may be provided beneath the electrodes, and the electrodes may be deposited through windows patterned in an electrically insulating layer, both omitted from FIGS. **1**A and **1**B for clarity), and each layer may comprise a plurality of layers.

A ridge optical waveguide (not shown) is formed by etching a ridge into at least the surface of the chip **100** opposite to the substrate **118**, and the ridge optical waveguide provides lateral guiding of light within the laser **102** and SOA **104**. In the case of a shallow ridge waveguide, it may be etched only part way through the overgrowth layer **124**. In the case of a deeper ridge waveguide, it may be etched through the overgrowth layer **124**, the optical guiding layer **122** and into the lower layer **120**. The ridge waveguide is dimensioned to support only a single transverse optical mode of the lasing wavelength, including within the passive section **114**.

The optical guiding layer **122** is intrinsic, undoped semiconductor material (i.e. not intentionally doped, i-type), and the optical guiding layer has a higher refractive index than the lower layer **120** or the overgrowth layer **124**. In at least the electrically drivable sections of the laser **106**, **108**, **110** and **112** (i.e. the sections configured to be electrically driven by current injection, in contrast to the passive section **114**, which is not configured to be electrically drivable), the lower layer **120** is doped with dopants of a first type (e.g. n-type). Similarly, in at least the electrically drivable sections of the laser **106**, **108**, **110** and **112**, the overgrowth layer **124** is doped with dopants of the opposite, second type (e.g. p-type). Accordingly, at least the electrically drivable sections of the laser **106**, **108**, **110** and **112** comprise p-i-n doped epitaxial structures.

The optical gain section **112** of the laser and the SOA **104** comprise an optical guiding layer **122** formed of a first material **130**. The first and second DBR sections **106** and **108**, and the phase control section **110** comprise an optical guiding layer formed of a second material **132**, to optimise their respective optical and electrical performance. The first material **130** is configured for being electrically driven by carrier injection to emit photons, in particular by stimulated emission, thereby amplifying light that passes through the corresponding sections **112** and **104**. The second material **132** is configured for being electrically driven by carrier injection to produce a refractive index change within the corresponding section **106**, **108** and **110**. With the exception of the passive section **114**, the laser **102** and SOA **104** are provided with an overgrowth layer **124** comprising a common third material **134** of the second dopant type (e.g. p-type). In the DBR sections **106** and **108**, the gratings **106**B and **108**B are formed by a corrugated boundary between materials having a different refractive index, being formed by etching a corrugated pattern into one material before overgrowing with a different material (e.g. in FIG. **1**A, a corrugated pattern is etched into the third material **134** before overgrowing with the further material **135**, which is also of the second dopant type).

The passive section **114** comprises an overgrowth layer **124** of material **136** of the second dopant type (e.g. p-type). The passive section **114** comprises a lower layer **120** of material **137** of the first dopant type (e.g. n-type).

The material **136** of the overgrowth layer **124** and/or the material **137** of the lower layer **120** within the passive section **114** may alternatively or additionally be undoped (i.e. not intentionally doped. The provision of undoped material **136** or **137** within the passive section **114** may reduce optical absorption within the passive section, enhancing laser performance. The material **136** of the overgrowth layer **124** may be grown by a selective area growth (SAG) epitaxial growth process, particular in the case that it differs from the material of the overgrowth layer in the electrically drivable sections **106**, **108**, **110** and **112**.

In use, current passed between each of the electrodes on the separate sections (e.g. the electrodes on the gain section **112**, phase section **110** and on the first DBR section **106** and the segmented electrodes on the DBR segments of the second DBR section **108**) and the back electrode **116**, typically spreads along the length of the optical waveguide by a few μm (i.e. less than 20 μm). The extent of this current spreading is dependent upon the epitaxial structure of the corresponding sections. Accordingly, the gain section electrode **112**A and phase section electrode **110**A may stop short of the edges of the gain section **112** and phase section **110**, to allow for corresponding electrical isolation gaps **113**, as is more clearly illustrated in FIG. **1**B, which shows the portion of the laser **102** bounded between the first and second DBRs **106** and **108**. The figures are schematic and not to scale, and accordingly exaggerate both the thickness of the epitaxially grown layers and the width of the electrical isolation gaps, for clarity. The epitaxial layers **120**, **122** and **124** built up on the substrate **118** are typically tens of nanometers thick, whilst the laser cavity is typically many millimeters long.

The passive section **114** is a non-driven region **115** of the optical waveguide within the laser cavity that is not configured to be electrically controlled, i.e. no electrical contact is provided to the upper surface. The passive section **114** has a different epitaxial structure to the gain section **112**, in respect of at least one epitaxial layer. Further, the passive waveguide section **114** is configured such that substantially no drive current may be passed through the optical guiding layer **122** of the passive waveguide section within the passive section, i.e. it is spaced apart from the portion of the gain section **112** covered by the gain section electrode **112**A by a narrow electrical isolation gap **113**.

The electrical isolation gaps **113** are parts of gain section **112** and phase control section **110** that are not provided with a covering electrical contact on the epitaxially grown side of the chip **100** (i.e. on the side of the chip opposite to the substrate, as opposed to any common earth electrode provided onto the substrate side of the chip in the electrical isolation gaps). Accordingly, the gain section **112** and phase control section **110** each comprise a driven region and non-driven regions **113** and **115** of the optical waveguide within the laser cavity, the driven and non-driven regions of the same section having the same epitaxial structure, and respectively being provided and not being provided with covering electrical contacts **112**A and **110**A on the epitaxially grown side of the chip **100**. Although no electrical contact is made onto the electrical isolation gap (on the epitaxially grown side of the chip), in use, the current that passes from the gain section electrode **110**A and the phase control section electrode **112**A through the optical guiding layer **122** to the common earth electrode **116**, will spread a little along the optical waveguide. The electrical isolation gaps **113** are at least wide enough for current that has spread into one side (adjacent the electrode) to be substantially zero at the other side (along the waveguide from the electrode).

Accordingly, the laser **102** has a composite non-driven region **115** within the optical waveguide of the lasing cavity, between the end reflectors of the laser cavity (e.g. between the first and second DBRs **106** and **108**). The composite non-driven region **115** is provided without a directly covering electrical contact on the epitaxial growth side of the chip, comprising the passive section **114** and the electrical isolation gaps **113**.

For clarity, in FIGS. **1**A and **1**B, the electrodes **106**A, **108**A_n, **110**A and **112**A have been shown contacting directly onto the overgrowth layer **124**. However, typically electrodes are provided onto contact regions **117** of a highly doped semiconductor contact layer, which the electrodes contact through windows etched in an electrically insulating dielectric layer **119**, as is shown in the expanded view of FIG. **10**. In this case, the extent of the electrical contact to the respective section is provided by the length of the respective contact region **117** (along the optical waveguide).

Accordingly, bounded by the first DBR section **106** and the second DBR section **108**, the optical cavity of the laser **102** is provided with a non-driven region **115** (that is an assembly of sub-regions that are not all adjacent) that is not provided with an electrical contact (either a metal electrode or highly doped contact region) or a grating, composed of electrical isolation gaps **113** and the passive waveguide section **114**. The composite non-driven region **115** has a length of at least 100 μm. The passive section **114** alone may have a length of at least 100 μm.

In FIGS. **1**A, **1**B and **1**C, the passive section **114** has a length of 100 μm and each electrical isolation gap **113** has a length of 10 μm (so that the separation between the gain section electrode **112**A and the phase section electrode **110**A is 20 μm), such that the non-driven region **115** has a length of 140 μm.

FIG. **1**D illustrates an alternative arrangement, in which a separate passive section is not provided between the first and second DBR sections **106'** and **108'**. In contrast, the electrical isolation gaps **113'** are larger than the electrical isolation gaps **113** of FIG. 1B, such that they extend well beyond the necessary width for current spread from the respective electrodes **112**A' and **110**A' to reduce to zero. Accordingly, the non-driven region **115'** comprises a plurality of electrical isolation gaps **113'**, and no epitaxially distinct passive section, and the benefit of narrower linewidth in the light output from the laser **102'** may be provided without a separate passive section by use of at least one electrical isolation gap that is longer than required for just the purpose of electrical isolation of adjacent regions beneath control electrodes.

The non-driven region has a length of at least 100 μm, and may have a length of at least 150 μm, at least 200 μm or at least 400 μm.

The passive section is at least 100 μm in length, and may have a length of at least 150 μm, at least 200 μm or at least 400 μm. In particular, lasers manufactured with passive sections of 450 μm and 900 μm length have been found to provide substantially lower Lorentzian linewidths than corresponding lasers without passive sections within the optical cavity of the laser.

In use (with reference to FIG. **1**A), the first DBR **106**, phase control section **110**, gain section **112** and at least some of the segments of the second DBR **108** are driven with respective currents I_r, $I\phi$, $I\alpha$, I_f^n and I_f^{n+1}. The SOA **104** is also driven with a current I_{SOA}, and amplifies the intensity of the light that is output from the optical cavity of the laser **102** through the partially reflective second DBR **108**, before the light is emitted through an output facet **138** of the chip **100**.

The optical cavity of the laser **102** extends between the DBR sections **106** and **108**, and penetrates into the DBR sections in accordance with the penetration distance of each DBR section, which in turn is dependent upon the strength of the grating **106**B and **108**B in each section (it is noted that alternatively one of the end reflectors of the laser cavity may be a reflective facet of the chip, for which there is no significant penetration distance). The presence of the length of the non-driven region **115** (including the passive section **114**) within the lasing cavity of the laser **102** provides an increased laser cavity optical path length and consequently an increased round-trip time for photons within the cavity, which reduces the spontaneous emission rate of the photons contributing to the lasing mode, and increases the population of photons within the laser cavity, resulting in the emission of light from the laser cavity that has a reduced Lorentzian linewidth, compared with a corresponding laser cavity without a non-driven region that is longer than necessary simply to provide electrical isolation (e.g. without a passive section).

The first and/or second DBR sections **106** and **108** are longer and have a weaker reflection per unit length than in the lasing cavity of a corresponding laser without such a lengthy non-driven region (e.g. without a passive section). This provides narrower reflective peaks with enhanced mode selectivity, in order to maintain single longitudinal cavity mode operation and to provide an acceptable side mode suppression ratio.

In the exemplary arrangement illustrated in FIG. **1**A: The first DBR section (rear DBR section) **106** comprises a phase-change grating **106**B producing a reflection spectrum comprising a comb of narrow reflective peaks, such as a grating described in U.S. Pat. No. 6,345,135. The second DBR section (front DBR section) **108** comprises a chirped grating **108**B with a pitch that varies continuously and monotonically, and in its un-tuned state produces a reflective peak with a wide, and relatively flat reflection spectrum. That relatively flat reflection spectrum is a composite reflection formed from the reflections of all of the different segments of the second DBR section, each of which individually provides a reflective peak that is significantly broader than each of the reflective peaks of the first DBR section. In use, the reflective peak of one segment of the second DBR section is tuned with respect to wavelength to overlap with that of another segment, to produce a reinforced reflective peak. Where a reflective peak of the first DBR section coincides in wavelength with the reinforced reflective peak of the second DBR section, a longitudinal cavity with lower round trip optical loss is formed, and when sufficient optical gain is provided, the laser primarily lases on a corresponding dominant mode within the wavelength range of low optical loss.

The grating **108**B of the second DBR section **108** may alternatively comprise a series of constant pitch steps. Short regions of constant pitch, separated by small pitch steps may be used to approximate to a continuous variation in pitch, with several steps in each segment of the second DBR. Alternatively, the grating within each segment of the second DBR **108** may have a constant pitch.

The lasing wavelength can be wavelength tuned as follows: very fine tuning is provided by thermal tuning with a thermo-electric cooler/heater element (not shown) to control the operating temperature of the chip **100**, which tunes the optical path length of the laser cavity; alternatively, or additionally, very fine tuning may be provided by tuning the optical path length of the phase control section **110**; fine tuning is provided by tuning the wavelength of the reflective comb of the first DBR **106**; and, coarse tuning is provided by additionally tuning the wavelength of the reinforced peak of the second DBR **108**, either through tuning the initial segments (closest to the gain section **112**), or by alternatively forming a reinforced reflective peak with a different combination of segments of the second DBR **108**. In each case the corresponding section of the laser **102** is tuned through carrier injection induced refractive index change. Further discussion of this tuning arrangement is found in U.S. Pat. No. 7,145,923.

During operation of a DBR laser, variations in electrical drive currents passing through sections of the laser arise due to statistical variations in the flow of charge carriers and electrical noise in the driving signals, for example due to electromagnetic interference and/or shot noise. Such drive current variations, and in particular variations in the drive current to the DBR sections (i.e. I_r and I_f''), result in variations in the wavelength of the laser output, which increase the linewidth/phase noise of the output light.

The dominant output wavelength of the laser is monitored by an electrical control system comprising a high speed control loop that provides electrical feedback to control electrodes on the laser (e.g. **110**A, **106**A and/or **108**A_i). Typically, the output light from the laser is sampled, the sampled beam is split, and one or both of the split beams is passed through a frequency discriminating component (e.g. an etalon) before being received at respective photodetectors. The relative intensities of electrical signals produced by the detected beams incident onto the photodetectors are compared, and used in a control algorithm to control the drive currents to the electrically drivable sections of the laser. U.S. Pat. Nos. 7,161,725 and 7,394,838 provide further details of a known arrangement of optical components for optically sampling the output light from a laser chip and a laser control system.

The phase control section **110** of the laser **102** is electrically driven (by current injection) by a drive current (I_Φ) comprising a DC current and a variable correction signal, from the control system to the phase section electrode **110**A. The phase control section **110** is shorter than in known monolithic tunable semiconductor lasers. In the illustrated arrangement of FIG. **1**A, the phase section is 20 μm long. Accordingly, the control system provides a larger variable correction signal to the phase control electrode than in known devices, which produces a larger refractive index change in the phase control section, in order to produce the required change in optical path length of the shorter phase control section **110**.

When current passes through the phase control section **110** it induces optical loss in the laser cavity. The shorter phase control section **110** can be driven with a higher DC current density than in known devices, whilst only inducing comparable optical loss in the laser cavity. Advantageously, driving with a higher DC current density reduces the carrier lifetime (i.e. the average time it takes for a minority charge carrier to recombine) within the phase control section **110**, which increases the frequency response bandwidth of the phase control section. The higher frequency response bandwidth enables the short phase control section **110** to respond to a more rapidly varying correction signal from the control system (e.g. the control system provides a correction signal having a bandwidth of at least 50 MHz, and preferably at least 100 MHz). Accordingly, high speed feedback control of the variable correction signal may be used to compensate for variations in the output wavelength of the laser arising as a result of electrical driving signal noise, particularly correcting for noise on the electrical driving signals to the DBR sections **106** and **108**. Such high speed correction actively suppresses the linewidth/phase noise of the output light from the laser **102**.

The phase control electrode **110**A contacts the phase control section **110** along a length of approximately 20 μm (along the length of the optical waveguide of the laser cavity), and the control system is configured to drive the phase control section **110** with a DC current of approximately 3 mA, which provides a frequency response bandwidth of approximately 150 MHz, when the laser is operated with a side mode suppression ratio (the relative intensity of the dominant longitudinal cavity mode of the laser compared with the largest side mode) of at least 40 dB.

In an alternative arrangement, the overgrowth layer **124** in the passive section **114** may comprise a material **136** with the same type of doping as the material **137** of the lower layer **120** in the passive section **114**, e.g. n-type material, which may be highly doped. In a yet further alternative, both materials **136** and **137** may be undoped.

The optical guiding layer **122** in the passive section **114** may have a higher refractive index than the optical guiding layer **122** in the electrically drivable laser sections **106**, **108**, **110** and **112**, which would further increase the optical path length of the laser cavity.

In FIG. **1**A, a single passive section **114** has been illustrated, which is located between the optical gain section **112** and the (second) DBR section **108**, which is partially transmissive and through which light exits the laser cavity towards the output facet **138**. That location for the passive section is particularly advantageous, since it is the location in which the greatest optical field strength is present within the laser cavity, in use. However, a passive section may be provided at an alternative location within the laser cavity (i.e. elsewhere between the first and second DBR sections **106** and **108**). Further, more than one passive section may be provided. For example, a passive section may alternatively or additionally be provided between the first DBR section and the phase section, or between the phase section and the gain section.

FIG. **2** illustrates a chip **200** with a monolithically integrated semiconductor laser **202** that has two passive subsections, **214***i* and **214***ii*, on either side of the gain section **212**, being the two locations of the laser cavity in which the optical field strength is typically greatest, in use. Also, in contrast to the passive section **114** of the laser **102** in FIG. **1**, the material **236** in the overgrowth layer **224** of the passive section **214***i* and **214***ii* is undoped. P-type doped material typically induces greater optical losses than n-type or undoped material. Accordingly, in the case that the overgrowth layer in the electrically drivable sections **206**, **208**, **210** and **212** is p-type, provision of n-type or undoped material **236** in the overgrowth layer **224** of the passive section(s) **214***i* and **214***ii* can reduce the optical loss in the laser cavity.

Although in the laser **102** illustrated in FIG. **1**A segmented electrodes **108**A, are provided on each of the segments of the DBR section, one or more electrodes may be omitted from the segments at one or both ends of the DBR section. In particular, the electrode (e.g. **108**A_1) or electrodes (e.g. **108**A_1 and **108**A_2) may be omitted from the DBR segment or segments in which the grating **108**B has the shortest pitch (when not driven). However, such a DBR segment without a segmented control electrode does not form part of the non-driven regions, as in contrast it comprises a segment of reflective Bragg grating.

By way of illustration, in FIG. **2**, an electrode (indicated in outline and labelled **208**A_1) is omitted from the DBR segment in which the grating **208**B has the shortest pitch (when not driven). Although not provided with an electrode, by which to be electrically controlled, the corresponding DBR segment is nonetheless regarded as part of the active DBR section **208**, since the reflection spectra of one or more other DRB segments (e.g. segments that are spectrally adjacent when not driven, e.g. the segment beneath electrodes **108**A_2) may be tuned into spectral cooperation with it.

FIG. **1**A illustrates a laser having both a non-driven region of at least 100 μm in length (e.g. having a passive section of at least 100 μm in length) and a phase section of less than 80 μm in length, that is operable with a high, frequency response bandwidth under single mode lasing conditions. However, it will be appreciated that alternatively a laser may be provided having only a non-driven region of at least 100 μm in length (e.g. having a passive section **314** of at least 100 μm in length) or a phase section **410** of less than 80 μm in length having a high frequency response bandwidth, as is illustrated in the monolithically integrated tunable semiconductor lasers **302** and **402** of FIGS. **3** and **4** respectively.

FIG. **5** illustrates a further arrangement of a monolithically integrated tunable semiconductor laser **502**, in which the overgrowth layer **524** of the passive section **514** is the same as the overgrowth layer **524** in the DBR sections **506** and **508** and the phase control section **510**. The chip **500** is also provided with an electrically insulating layer (e.g. dielectric) **540** across the passive section **514**. Such an electrically insulating layer **540** can enable the provision of an electrode or electrical tracking **542** to pass across the passive section **514**, without electrically interacting with the passive section. Such a design can facilitate a lower level of complexity in the manufacture of the chip **500**. For example, if the passive section is provided adjacent the phase control section, and an electrically insulating layer is provided on the passive section, then a longer phase section electrode may be provided which covers both the passive and phase control section, but which only electrically contacts the laser in the phase control section.

FIG. **6** illustrates an optoelectronic chip **600** having an alternative design of monolithically integrated semiconductor laser **602**. The laser **602** differs from that of FIG. **1**A by the second DBR section **608** being tunable by a single control electrode **608**A. This arrangement is suitable for a Vernier-tuned laser **602**, in which the first and second DBR sections **606** and **608** each provide a comb of narrow reflective peaks, but which are differently spaced, so that by relative tuning it is possible to tune the DBR sections such that a reflective peak from each DBR section is tuned to the same wavelength, producing a low round trip optical loss within the cavity at that wavelength, in order to control the lasing of the cavity to that wavelength when sufficient optical gain is provided by the gain section **612**. Again, a non-driven region is provided by the electrical isolation gaps **613** and the passive section **614**.

FIG. **7** illustrates a schematic cross-sectional view of an optoelectronic semiconductor chip **700** having a tunable semiconductor laser **702** optically integrated on a common optical waveguide with a semiconductor optical amplifier (SOA) **704**, which is outside the cavity of the laser. The laser **702** has first and second distributed Bragg reflector (DBR) sections **706** and **708** bounding a phase control section **710**, an optical gain section **712** and a grounded passive section **714**. The sections **706**, **708**, **710**, **712** and **714** of the laser **702** are monolithically integrated on the common semiconductor chip **700**.

The chip **700** is provided with a grounded common earth electrode **716** (also referred to as the "back electrode") onto the substrate **718**. The first DBR section **706**, the phase control section **710**, the optical gain section **712**, and the SOA **704** are provided with respective electrical control electrodes, **706**A, **710**A, **712**A and **704**A. The grounded passive section **714** is provided with an electrically grounded electrode **714**A onto the side of the chip **700** opposite to the common earth electrode **716** (e.g. in the case of a ridge waveguide laser, the electrically grounded electrode **714**A is provided onto the ridge). No reflective Bragg grating is provided within the grounded passive section **714**. The first DBR section **706** comprises a reflective Bragg grating **706**B that produces a reflection spectrum with a comb of reflective peaks. The second DBR section **708** comprises a reflective Bragg grating **708**B with a monotonically chirped grating pitch, with respective sub-electrodes **708**A_1, **708**A_2, etc. provided on segments of the second DBR section arranged along the optical waveguide.

As is conventional in optoelectronic structures, the chip **700** comprises a common substrate **718** and a series of epitaxially grown layers successively built up on the substrate, being a lower layer **720**, an optical guiding layer **722**, and an overgrowth layer **724**. Further layers may also be provided (e.g. a patterned layer of highly doped material may be provided beneath the electrodes, and the electrodes may be deposited through windows patterned in an electrically insulating layer, both omitted from FIG. **7** for clarity), and each layer may comprise a plurality of layers.

A ridge optical waveguide (not shown) is formed by etching a ridge into at least the surface of the chip **700** opposite to the substrate **718**, and the ridge optical waveguide provides lateral guiding of light within the laser **702** and SOA **704**. In the case of a shallow ridge waveguide, it may be etched only part way through the overgrowth layer **724**. In the case of a deeper ridge waveguide, it may be etched through the overgrowth layer **724**, the optical guiding layer **722** and into the lower layer **720**. The ridge waveguide is dimensioned to support only a single transverse optical mode of the lasing wavelength, including within the grounded passive section **714**.

The optical guiding layer **722** is intrinsic, undoped semiconductor material (i.e. not intentionally doped, i-type), and the optical guiding layer has a higher refractive index than the lower layer **720** or the overgrowth layer **724**. In at least the electrically drivable sections of the laser **706**, **708**, **710** and **712** and in the grounded passive section **714**, the lower layer **720** is doped with dopants of a first type (e.g. n-type). Similarly, in at least the electrically drivable sections of the laser **706**, **708**, **710** and **712** and in the grounded passive section **714**, the overgrowth layer **724** is doped with dopants of the opposite, second type (e.g. p-type). Accordingly, at least the electrically drivable sections of the laser **706**, **708**, **710** and **712** comprise p-i-n doped epitaxial structures, enabling current injection into the respective portion of the optical guiding layer **720**. Further, the grounded passive section **714** comprises a p-i-n doped epitaxial structure, enabling electrical charge carriers (i.e. electrons and holes) that have been photogenerated by optical absorption to flow out from the respective portion of the optical guiding layer **720**.

The optical gain section **712** of the laser and the SOA **704** comprise an optical guiding layer **722** formed of a first material **730**. The first and second DBR sections **706** and **708**, the phase control section **710** and the grounded passive section **714** comprise an optical guiding layer formed of a second material **732**, to optimise their respective optical and electrical performance. The first material **730** is configured for being electrically driven by carrier injection to emit photons, in particular by stimulated emission, thereby amplifying light that passes through the corresponding sections **712** and **704**. The second material **732** is configured for being electrically driven by carrier injection to produce a refractive index change within the corresponding section **706**, **708** and **710**. The second material **732** is also suited to use in the optical guiding layer of the grounded passive section **714**, having lower optical absorption than the first material **730**. The laser **702** and SOA **704** are provided with an overgrowth layer **724** comprising a common third material **734** of the second dopant type (e.g. p-type). Accordingly, in the illustrated laser **702**, the grounded passive section **714** and the phase section **710** have the same epitaxial structure. In the DBR sections **706** and **708**, the gratings **706**B and **708**B are formed by a corrugated boundary between the third material **734** and a further material **735** (e.g. also of the second dopant type) having a different refractive index, being formed by etching a corrugated pattern into the third material **734** before overgrowing with the further material **735**.

The waveguide in the grounded passive section **714** is dimensioned to support only a single transverse mode of the laser cavity.

The grounded passive section **714** is a non-driven region of the optical waveguide within the laser cavity that is not configured to be electrically controlled with a drive current. However, the grounded passive section **714** is provided with an electrode **714**A on its upper surface (i.e. the opposite side of the chip **700** from the common earth electrode **716**) that is electrically connected to electrical ground (as is the common earth electrode **716**) through a low resistance pathway (e.g. the pathway has a sufficiently low resistance to prevent the maximum photogenerated bias arising between the electrically grounded passive section electrode **714**A and the common earth electrode **716** from reaching the switch-on voltage of the p-i-n diode structure in the grounded passive section **714**, e.g. maintaining a bias of less than 0.5V, preferably less than 0.25V, and more preferably less than 0.1V). For example, the common earth electrode **716** of the optoelectronic semiconductor chip **700** may be bonded to an electrically grounded tile electrode **770**A on an underlying tile **770** (e.g. bonded with solder **772** or electrically conductive cement), and the electrode **714**A of the grounded passive section **714** may be electrically connected to the tile electrode by a wire bond **774** or by an electrically conducting hole (also known as a "via", and not illustrated) through the chip **700**.

Accordingly, the laser **702** has a composite non-driven region within the optical waveguide of the lasing cavity, between the end reflectors of the laser cavity (e.g. between the first and second DBRs **706** and **708**), comprising the grounded passive section **714** and the electrical isolation gaps in the driven sections **706**, **708** and **710** and **712**.

Accordingly, bounded by the first DBR section **706** and the second DBR section **708**, the optical cavity of the laser **702** is provided with a non-driven region (that is an assembly of sub-regions that are not all adjacent) that is not electrically driven (in use) and is not provided with a grating, composed of electrical isolation gaps and the grounded passive waveguide section **714**. The composite non-driven region has a length of at least 100 μm. The grounded passive section **714** alone may have a length of at least 100 μm. In the exemplary laser **702** of FIG. **7**, the grounded passive section **714** has a length of 450 μm and each electrical isolation gap has a length of 10 μm (so that the non-driven region has a length of at least 500 μm).

The grounded passive section is at least 100 μm in length, and may have a length of at least 150 μm, at least 200 μm or at least 400 μm. In particular, lasers manufactured with grounded passive sections of at least 450 μm length have been found to provide substantially lower total linewidths than corresponding lasers without grounded passive sections within the optical cavity of the laser.

Aside from the differences discussed above, the structure and electrical operation of the laser **702** of FIG. **7** is similar to the structure and electrical operation of the laser **102** of FIG. **1**A. Accordingly, the optical cavity of the laser **702** extends between the DBR sections **706** and **708**, and penetrates into the DBR sections in accordance with the penetration distance of each DBR section, which in turn is dependent upon the strength of the grating **706**B and **708**B in each section (it is noted that alternatively one of the end reflectors of the lase cavity may be a reflective facet of the chip, for which there is no significant penetration distance). The presence of the length of the non-driven region (including the grounded passive section **714**) within the lasing cavity of the laser **702** provides an increased laser cavity optical path length and consequently an increased round-trip time for photons within the cavity, which reduces the spontaneous emission rate of the photons contributing to the lasing mode, and increases the population of photons within the laser cavity, advantageously resulting in the emission of light from the laser cavity that has a reduced Lorentzian linewidth, compared with a corresponding laser cavity without a non-driven region that is longer than necessary simply to provide electrical isolation (e.g. without a grounded passive section).

The presence of the grounded passive section further enhances the optical performance of the laser, relative to the provision of a corresponding passive section that is not electrically grounded both above and below. Optical absorption within the grounded passive section generates electrical carriers. However, the presence of photogenerated carriers would change the refractive index of the passive section in a way that would reduce the rate of optical absorption, causing a cycle that produces oscillations in the emission frequency of the emitted light λ. Further, photogenerated carrier would also recombine spontaneously within the optical guiding layer, which would contribute to the phase noise characteristic of the emitted light λ. Accordingly, by having a p-i-n structure that is grounded both above and below, the grounded passive section enables photogenerated electrical charge carriers to flow rapidly out of the grounded passive section, thereby advantageously reducing the total linewidth of the emitted light λ, in particular reducing the contribution from shot noise.

The lower layer **720**, optical guiding layer **722** or overgrowth layer **724** in the grounded passive section **714** may have a higher refractive index than the corresponding layers in one of the DBR sections **706** and **708**, or in the phase section **710**, which would further increase the optical path length of the laser cavity.

In FIG. **7**, a single grounded passive section **714** has been illustrated, which is located between the optical gain section **712** and the (second) DBR section **708**, which is partially transmissive and through which light exits the laser cavity towards the output facet **738**. That location for the grounded passive section is advantageous, since it is the location in which the greatest optical field strength is present within the laser cavity, in use. However, a grounded passive section may be provided at an alternative location within the laser cavity (i.e. elsewhere between the first and second DBR sections **706** and **708**). Further, more than one grounded passive section may be provided. For example, a grounded passive section may alternatively or additionally be provided between the first DBR section and the phase section, or between the phase section and the gain section.

FIG. **8** illustrates a chip **800** with a monolithically integrated semiconductor laser **802** that has two grounded passive sub-sections, **814***i* and **814***ii*, with one grounded passive sub-section provided along the length optical waveguide, next to each end of the optical gain section **812**. Advantageously, providing a sub-section **814***i* and **814***ii* of the grounded passive section on each side of the optical gain section **812** enables a distribution of photons throughout the laser cavity that enables further enhanced reduction in the total linewidth of emitted light λ.

The figures have illustrated the inclusion of a passive section (e.g. including a grounded passive section) within a DBR laser having DBRs at each end of the laser cavity. However, it will be appreciated that a passive section (grounded or otherwise) or a phase section having a frequency response bandwidth of greater than 50 MHz under single mode lasing conditions may be included within a laser in which one end of the laser cavity is provided by a DBR section and the other end is provided by a facet reflection.

Although the figures have illustrated the inclusion of a DBR laser having an unbranched optical waveguide, it will be appreciated that the DBR laser may have a branched optical waveguide. For example the DBR laser may have a Y-shaped optical waveguide, with a DBR reflector at the end of each waveguide arm, being optically coupled to a common reflector (e.g. facet reflector) by a waveguide splitter (e.g. 1×2 multimode interference coupler).

The figures have illustrated the inclusion of an unbranched passive section within a laser. However, it will be appreciated that a laterally (in plane) branched passive section may also be included within a laser.

The figures provided herein are schematic and not to scale.

Throughout the description and claims of this specification, the words “comprise” and “contain” and variations of them mean “including but not limited to”, and they are not intended to (and do not) exclude other moieties, additives, components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

Features, integers, characteristics, compounds, chemical moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

The reader’s attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

The invention claimed is:

1. A monolithically integrated, tunable semiconductor laser with an optical waveguide, comprising a laser chip having epitaxial layers on a substrate and having

first and second reflectors bounding

an optical gain section and

a passive section that has a length of at least 100 μm,

wherein at least one of the reflectors is a distributed Bragg reflector section comprising a grating and configured to have a tunable reflection spectrum,

wherein the laser is provided with a common earth electrode that is electrically grounded,

wherein control electrodes are provided on the optical waveguide in at least the optical gain section and the at least one distributed Bragg reflector section,

wherein the passive section is provided with a passive section electrode that electrically contacts the opposite side of the optical waveguide from the substrate, the passive section is configured not to be drivable by an electrical control signal, and no grating is present within the passive section, and

wherein the passive section is a grounded passive section in which the passive section electrode is an electrically grounded electrode that electrically contacts the passive section, and the passive section electrode and the common earth electrode electrically contact opposite sides of the optical waveguide.

2. The monolithically integrated, tunable semiconductor laser according to claim **1**, wherein the common earth electrode is provided on the substrate, the common earth electrode is bonded to a mounting element electrode provided on a mounting element, and the passive section electrode is electrically connected to the mounting element electrode.

3. The monolithically integrated, tunable semiconductor laser according to claim **1**, wherein an electrically insulating layer is provided on the optical waveguide in the passive section, and the passive section electrode is provided on the electrically insulating layer.

4. The monolithically integrated, tunable semiconductor laser according to claim **1**, wherein the grounded passive section comprises a p-i-n doped epitaxial structure.

5. The monolithically integrated, tunable semiconductor laser according to claim **1**, wherein the laser comprises a substrate, a lower layer on the substrate, an overgrowth layer and an optical guiding layer between the lower layer and the overgrowth layer,

wherein the optical waveguide has an optical phase control section bounded by the first and second reflectors, and

the phase control section and the passive section comprises a common overgrowth layer and/or lower layer.

6. The monolithically integrated, tunable semiconductor according to claim **1**, wherein the laser comprises a plurality of passive sub-sections.

7. The monolithically integrated, tunable semiconductor laser according to claim **1**, wherein a reflector is an output reflector that is configured for optical output from the laser, and the passive section or a passive sub-section is located between the optical gain section and the output reflector.

8. The monolithically integrated, tunable semiconductor laser according to claim **1**, wherein the optical waveguide has an optical phase control section bounded by the first and second reflectors, and the passive section or a passive sub-section is located between the optical gain section and the optical phase control section.

9. The monolithically integrated, tunable semiconductor laser according to claim **1**, wherein the passive section has a length of at least 150 μm.

10. The monolithically integrated, tunable semiconductor laser according to claim **9**, wherein the passive section has a length of at least 200 μm.

11. The monolithically integrated, tunable semiconductor laser according to claim **10**, wherein the passive section has a length of at least 400 μm.

12. A monolithically integrated, tunable semiconductor laser array comprising a plurality of lasers according to claim **1** optically coupled to a common optical output.

13. An optical transmitter module comprising a monolithically integrated, tunable semiconductor laser according to claim **1**, or an array thereof, and control electronics configured to control the operation of the monolithically integrated, tunable semiconductor laser or the array thereof.

14. The optical transmitter module according to claim **13**, wherein the control electronics comprises a control loop configured to sample the wavelength of light output from the laser or laser array and to provide electrical feedback to control electrodes provided on the laser or laser array.

15. A monolithically integrated, tunable semiconductor laser with an optical waveguide, comprising a laser chip having epitaxial layers on a substrate and having

first and second reflectors bounding

an optical gain section and

a grounded passive section that has a length of at least 100 μm,

wherein at least one of the reflectors is a distributed Bragg reflector section comprising a grating and configured to have a tunable reflection spectrum,

wherein the laser is provided with a common earth electrode that is electrically grounded,

wherein control electrodes are provided on the optical waveguide in at least the optical gain section and the at least one distributed Bragg reflector section,

wherein the grounded passive section is provided with a passive section electrode that electrically contacts the opposite side of the optical waveguide from the substrate and that is electrically connected to the common earth electrode, and no grating is present within the grounded passive section,

wherein the passive section electrode is an electrically grounded electrode that electrically contacts the grounded passive section, and the passive section electrode and the common earth electrode electrically contact opposite sides of the optical waveguide.

16. A monolithically integrated, tunable semiconductor laser on a substrate and having an optical gain section, an optical phase control section, a common earth electrode that is electrically grounded, and a grounded passive section that has a length of at least 100 μm, the grounded passive section bounded at one end by a tunable first Bragg reflector in the form of a distributed Bragg reflector adapted to produce a comb of reflective peaks and at the other end by a tunable second distributed Bragg reflector, the second distributed Bragg reflector being adapted to reflect at a plurality of wavelengths, wherein one or more wavelengths of reflective peaks of the first distributed Bragg reflector substantially coincide with one or more wavelengths at which the tunable second distributed Bragg reflector reflects prior to each of the first and second distributed Bragg reflectors being tuned, and wherein the second distributed Bragg reflector is capable of being tuned selectively through discrete segments so that one or more segments of the second distributed Bragg reflector can be tuned to a lower wavelength to reflect with a further segment of the second distributed Bragg reflector reflecting at that lower wavelength to enhance the reflectivity at that lower wavelength, the lower wavelength substantially coinciding with a peak of the first distributed Bragg reflector, thereby capable of causing the laser to lase at that lower wavelength, wherein the passive section is provided with a passive section electrode that electrically contacts the opposite side of the optical waveguide from the substrate, the grounded passive section is configured not to be drivable by an electrical control signal, and no grating is present within the grounded passive section, wherein the passive section electrode is an electrically grounded electrode that electrically contacts the grounded passive section, and the passive section electrode and the common earth electrode electrically contact opposite sides of the optical waveguide.

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